Institute of Astronomy, National Central University

PHD QUALIFYING EXAMINATION — GALACTIC AND EXTRAGALACTIC ASTROPHYSICS

31st May, 2005

Please answer 5 out of the following 7 problems.

(1) (20 points)
   (a) (4 points) Describe Olbers's paradox.
   (b) (8 points) It might be argued that the inverse square law for light would provide a solution to Olbers' paradox. To see that this is not so, consider a uniform distribution of stars with n stars per unit volume, each of luminosity L. Imagine that two thin spherical shells of stars with radii r_1 and r_2 are centered on Earth; let the thickness of each shell be Δr. Show that the same energy flux reaches Earth from each shell.
   (c) (8 points) Describe how to resolve Olbers' paradox in the context of modern cosmology.

(2) (20 points)
   (a) (5 points) Hubble discovered the expansion of the universe. Write down Hubble's law and define Hubble's constant H_0.
   (b) (5 points) Many of the properties of an isotropic cosmological model can be derived using a simple Newtonian formalism. In particular, consider a spherical region in the Universe of radius r and mass M. An object of mass m lying at the edge of this sphere only feels the gravitational influence of the material within the sphere. Show that the total energy of the mass m can be written as

$$\frac{1}{2}m\dot{\mathbf{r}}\cdot\dot{\mathbf{r}} - \frac{GMm}{r} = E = \text{constant}\,.$$

   (c) (10 points) If the Universe is critically-bound, the total energy of the object will be zero. Assuming radial motion only, integrate this equation forward in time from the Big Bang ($r = 0$, $t = 0$) to the present day when $t = t_{\rm now}$, show that $t_{\rm now} = (2/3)H_0^{-1}$.

(3) (20 points)
   (a) (5 points) Express Galactic longitudinal, l, as a function of the Galactocentric polar coordinates, (R, ϕ).
   (b) (15 points) Let $R_{\rm in}$ be the inner radius of the middle disk and assume that the circular speed is constant at v_c at radii in the interval $R_{\rm in} \le R \le R_0$. Show that the maximum line-of-sight velocity at which 21-cm emission from the middle disk will be observed at longitude l is

$$v_{\rm max} = \left(\frac{R_0}{R_{\rm in}} - 1\right) v_c \sin l\,.$$

(4) (20 points)

(a) (5 points) Galaxies collide with one another, but stars do not, at least very unlikely. Please explain why. [Hint: Compare the size and the separation of objects.]

(b) (15 points) When an object M is moving through an infinite collection of stars, gas clouds, and dark matter with a constant mass density ρ, assuming the mass of each object in the background "sea" of material is much less than M, so M continues moving in a straight line instead of being deflected, but M will still be slowed down. Why? Please explain this effect which is referred to as "dynamical friction", and write down the approximate formula for the "dynamical friction force", in terms of the speed of the object v, the mass M, and the background density ρ.

(5) (20 points)

Gamma-Ray Bursts (GRBs) are divided into two sub-categories, the "short" bursts and the "long" bursts. How is this division defined? What is the most popular current theory for the nature of the short and long GRBs? In the early 1990's, Gamma-Ray Bursts (GRBs) were thought to be related to neutron stars. Please explain why, in terms of the observed "flux rise time" and the observed spectral lines in high energy regions. From more than 2,000 GRBs detected by the Compton Gamma-Ray Observatory during 1991-2000, what have we learned about the overall distribution of GRBs? From the definition of fluence (integrated flux), how do we estimate if there is an edge to the distribution of the GRBs or not? What conclusion can we reach (in terms of distance from us) when we have information on both the distribution pattern and the existence of an edge of GRBs? How was the optical image of GRB990123 obtained? What have we learned from the optical fading rate in this object?

(6) (20 points)

In the program "International AGN Watch" starting early 1990s, scientists were able to picture the geometry of the inner region of the black hole accretion disk. The first object being observed with this campaign is NGC5548. The technique used in this global monitoring effort is called the "reverberation mapping", using both IUE satellite (for the UV region) and many ground based optical telescope (for the optical region).

(a) (6 points) Please describe the theory and the method of the "reverberation mapping" technique.

(b) (7 points) Please describe the central region of an Active Galactic Nuclei (AGN), preferably using a figure showing the assumed black hole, the accretion disk, the broad line region, and the narrow line region.

(c) (7 points) What have we learned about the distribution of the gas with various ionization levels?

(7) (20 points)

Please describe the so-far very popular "unification scenario" of AGNs and QSOs. What is the major parameter that makes the difference among all the AGNs and QSOs? There has been one case of Seyfert 2 observation which supports this scenario. People find that some Seyfert 2 galaxies are actually "hidden Seyfert 1 galaxies". Please explain how this discovery was made, and the scientific significance of this discovery.